# RISK ANALYSIS FOR TEMPORARY STORAGE OF AMMUNITION IN COMBAT AREAS

**Twenty-Fifth DOD Explosives Safety Seminar**

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**by**

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# RISK ANALYSIS FOR TEMPORARY STORAGE OF AMMUNITION IN COMBAT AREAS

BY

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Many elements of the Army must store quantities of ammunition and other explosives in order to perform their basic mission. Department of Defense (DOD) regulations provide safety standards to minimize the risk and consequences of an accidental explosion of stored ammunition (Reference 1). For operations in combat areas, the standards are less restrictive, and allow reduced separation distances (Quantity-Distance, or Q-D's) between the ammunition storage and personnel, structures, vehicles, or other assets. Furthermore, a unit commander may determine that even those allowable reductions in Q-D's cannot be met without adversely affecting his unit's combat readiness.

To make the most intelligent decision, the field commander must weigh the increase in risk to his troops and equipment that would be created by compromising the safety standards, against the tactical benefits to be gained. At present, there is no ready reference guide to help the commander make such an "on-the-spot" judgement. The purpose of this study is to develop realistic, practical, and applicable guidelines for field commanders which will describe, in tangible, quantitative terms, the increased risk incurred by specific deviations from the prescribed ammunition storage safety standards (i.e., the Q-D values) in combat scenarios.

## PROBLEM DEFINITION

The problem may be described by the example shown in Figure 1. Items A and B are storage units of ammunition (open stacks, truckloads, etc.) and Item T is a "target" that is vulnerable to explosion hazards. Given an explosion at A, $P_A$ is the probability that a target T is damaged (or in the case of personnel, injured) by an explosion at A. $P_B$ is the probability of damage or injury to target T by the effects of an explosion at B. $P_{B|A}$ is the probability that an explosion at A causes B to sympathetically detonate. The problem of compounded probabilities is simplified by the fact that, although the detonation of B is dependent on the detonation of A, the hazardous effects (particularly fragmentation, which is the

main focus of this study) may be considered as independent events. Statistically, this means that the probability of damage from each event can be determined independently and then combined. The solution to the problem is based on a "favorable outcome," which in this case is the probability of not getting hit, or survival. Survival for A is expressed as $P_{SA} = 1 - P_A$, and for B as $P_{SB} = 1 - P_B$. For the simple case where both A and B explode, the probability of a "hit" at T is expressed as:

$$P_T = 1 - P_{S(A\&B)} = 1 - ( 1 - P_A ) * ( 1 - P_B )$$

Notice that $P_T = 0$ when $P_A$ and $P_B = 0$, and $P_T = 1$ when $P_A$ and $P_B = 1$. $P_T = 0.75$ when $P_A$ and $P_B = 0.5$.

In the above example, it was assumed that storage units A and B both explode. This is based on the conditional probability $P_{B|A}$ (that B will explode, given an explosion at A). Here the "favorable outcome" relates to the probability that the detonation of A will also cause a sympathetic detonation of B. The conditional probability, if $P_A$ is not 0, may be expressed as $P_A * P_{B|A}$ (reference 2). Thus:

$$P_T = 1 - ( 1 - P_A ) ( 1 - P_A * P_{B|A})$$

Given these relationships, all that remains is to determine the individual probabilities.

## EXPLOSION EFFECTS

The possible causes for sympathetic detonation of a second ammo stack are airblast, fragment impact, and slow cook-off of ammunition due to fire (caused by fire-brands thrown by the initial explosion). The probability of damage or injury to a target stems from two sources - airblast and fragments/debris from the explosion(s).

Recent tests indicate that airblast is probably not a direct factor in sympathetic detonation of individual ammo stacks. Also, airblast can be easily predicted for a known net explosive weight (NEW), which represents a "worst case" scenario - the mass detonation of the entire stack. Therefore this study concentrates on the fragment hazard.

## COMPUTER MODELING

The Q-D Fragment Hazard (FRAGHAZ) Computer Program, developed by the U.S. Naval Surface Warfare Center, was used to address the fragment hazard in this analysis. FRAGHAZ (Reference 3) employs fragment data obtained from small-scale tests that represented large stacks of munitions. Among the data sets available for use in the program are those for MK-82 GP bombs and 155mm projectiles. To determine the hazard to a specified target, complete trajectories are calculated for each fragment identified in the small-scale test data set, using random variables to determine the hazard to a specified target. A number of Monte Carlo simulations (usually 60) are run to statistically evaluate a given problem. The program's output is in the form of fragment densities and probabilities of target hits.

Because of the many types of ammo used by the military, a worst case donor munition (for fragmentation purposes) was chosen. The general consensus in the explosive safety community was that, for this study, a representative worst case munition is the Comp B-filled M107 155-mm projectile.

## DAMAGE CRITERIA

Since this study deals with temporary encampments in combat areas, the main concern is with hazards to personnel, rather than damage to permanent buildings. The DOD standards define a hazard criterion of one hazardous fragment impact per 56 square meters. Since the FRAGHAZ program calculates statistically for a number of simulations, and we must have some reference, we chose the 90 percentile statistic, which is also used in the DOD standard. Also, the Q-D's defined by the standards are based on the acceptance of some small degree of risk - specifically, a one percent probability of a hit. This number was used here in determining an acceptable probability of injury.

The remaining problem is to define a hazardous fragment. Previously this had been accepted as a fragment with an energy of 79 joules (58 ft-lb) or more. Recently, however, the standards consider skin penetration as an injury criterion, and this has been incorporated into the FRAGHAZ program (reference 4). For 155mm projectiles in the situations considered in this study, comparisons showed no measurable difference for calculations made using the skin penetration criteria than for those using the 79-joule criteria.

## STORAGE METHODS

The fact that this analysis is concerned only with the field storage limits the number of ammo storage methods that need to be considered. The storage

methods that would most likely be used at a temporary field site are uploaded trucks or ammo stacked on the ground surface. At the recommendation of the U.S. Army Technical Center for Explosives Safety, the Palletized Load System (PLS) was considered as the method of storage. Several possible PLS configurations are shown in Figure 2. In some cases, barricades may be constructed between ammo trucks or munition stacks, or the trucks could be parked in trenches (either covered or uncovered), both to prevent sympathetic detonations of stacks by fragments from an accidental detonation of an adjacent stack, as well as to reduce the hazards to nearby personnel from such a detonation. The above conditions dictate several factors that can influence the probabilities of a fragment hit on a target:

(1) Standoff height of the ammo stack above ground level (either pallet height or height of a truck body).

(2) Number of stacked layers (tiers) of ammo.

(3) Total number of projectiles in a stack.

(4) Use of barricades between stacks.

The FRAGHAZ calculations indicated that, for all practical purposes, the standoff height of a stack (Figure 3) and the number of tiers in a stack (Figure 4) have no effect on fragment hazard. The main factor defining the fragment hazard is the number of projectiles (Figure 5) on the face of the stack, which can be equated to a unique NEW (less than the NEW of the entire stack) by assuming that the stacks contain PLS loads.

The FRAGHAZ program has been adapted to evaluate the influence of barricades (reference 5). Figure 6 shows the results of a FRAGHAZ calculation, which indicate the extent that the fragment hazard can be reduced by the use of barricades. Notice that, at far distances, a sloped barricade (45 degrees) provides less reduction in the probability of hit than a vertical-faced barricade, but the risk is still well below the acceptable limit. These calculations are based on the assumption that fragments are stopped by the barricades or, in the case of the sloped barricades, may ricochet off and be deflected upward at a steeper trajectory angle, thus accounting for the higher hit probabilities at ranges beyond 270 meters. Barricades are known to suppress fragment dispersion. However, although these calculations are believed to be relatively accurate, there is not sufficient data available to verify the calculation results.

## INCREASE IN RISK

If we define Q-D's based on the one percent probability of a hit as calculated by FRAGHAZ, the information presented in Figure 5 may be displayed as increased risk vs. percent reduction in Q-D (Figure 7). Figure 8 shows the increased risk vs. percent reduction in Q-D using the Q-D's recommended in Chapter 10 of the DOD Ammunition and Explosives Safety Standards as departure points. Table 1 summarizes the increase in risk due to Q-D violations for open storage of ammo in a theater of operations.

Determining the probability of sympathetic detonation of a second ammo stack by the explosion of a nearby stack is a much more difficult problem. There has been much discussion recently in the explosives safety community about selection of a "worst case" acceptor munition (i.e., one that is most susceptible to detonation by a fragment impact). Unfortunately, the most probable candidate is considered too dangerous to test in the detail required. Therefore many assumptions are necessary to investigate this portion of the problem. It appears that the main factors affecting the probability of a detonation due to a fragment impact are the fragment mass and impact velocity. However, many other factors - e.g., fragment shape, impact angle, fragment temperature, whether the fragment penetrates the target or not - all contribute to the possibility of causing detonation.

The FRAGHAZ program is designed to predict the probability that a fragment with a certain kinetic energy will hit a given target at some distance from an explosion. Since we do not have the data necessary to determine the energy required to cause a detonation by an impact, Figure 9 shows the probability of a target (in this case a PLS ammo stack) being hit by fragments having a range of energy levels. Curve 1 in Figure 9 shows the probability of a hit vs. distance for all fragments. Curve 2 shows the probability of a hit by a fragment with a kinetic energy of 1500 joules (1100 ft-lbs) or greater. Curve 3 is for fragments with a kinetic energy of 7450 joules (5500 ft-lbs) or greater. The calculations indicate that the larger, high-energy fragments are only found at the closer ranges. Curve 4 shows the effects of a barricade on the probability of hit for all fragments. The calculations indicate a near-zero hit probability for high-energy (71,500 joules) fragments, implying that a barricade can be very effective in reducing the risk of sympathetic detonations of adjacent stacks. Recent tests (Reference 6) have confirmed that a properly constructed barricade can prevent a sympathetic detonation of a nearby ammo stack.

Another factor complicating the problem is that distances between stacks or parked uploaded trucks may be much closer than the FRAGHAZ program is currently set up to handle. However, as more information becomes available, and the problem becomes more clearly defined, modifications to FRAGHAZ should

allow this type of calculation, since fragment trajectories are calculated throughout their entire flight history. It is recommended that experimental data be collected to augment calculations of probability of detonation due to fragment impact.

## SUMMARY

While not exhaustive in scope, the results of this analysis provide a useful indication of the increased risk to personnel incurred by violating prescribed Q-D's in theaters of operations. For example, decreasing the spacings between uploaded ammo trucks by 20 percent effectively doubles the risk of fragment injuries to personnel. A decrease of 30 percent causes the risk to increase by a factor of three. Additional analyses, along with verification by experimental data, should lead to comprehensive guidelines that may be incorporated in future revisions of the DOD standards.

## ACKNOWLEDGEMENTS

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Also, the author would like to thank Mr. Michael Swisdak, Naval Surface Warfare Center, and Mr. Frank McClesky, Booz-Allen and Hamilton, Inc., for modifying the FRAGHAZ program to perform the calculations that made this study possible.

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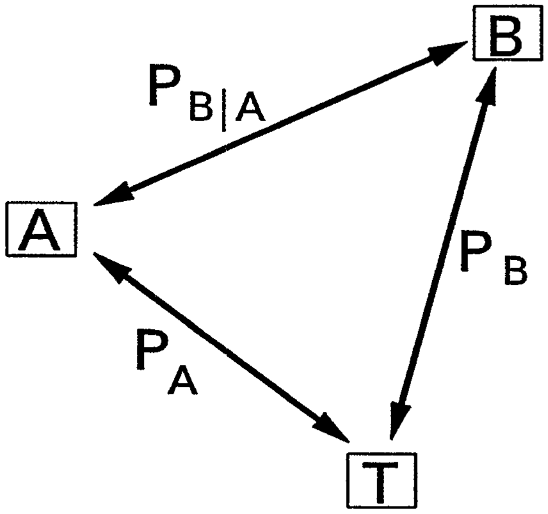


A & B ARE AMMO STACKS
T IS THE TARGET

$P_A$ = PROBABILITY OF HIT AT T BY EXPLOSION AT A

$P_B$ = PROBABILITY OF HIT AT T BY EXPLOSION AT B

$P_{B|A}$ = PROBABILITY OF EXPLOSION AT B DUE TO EXPLOSION AT A

FIGURE 1. PROBLEM DEFINITION

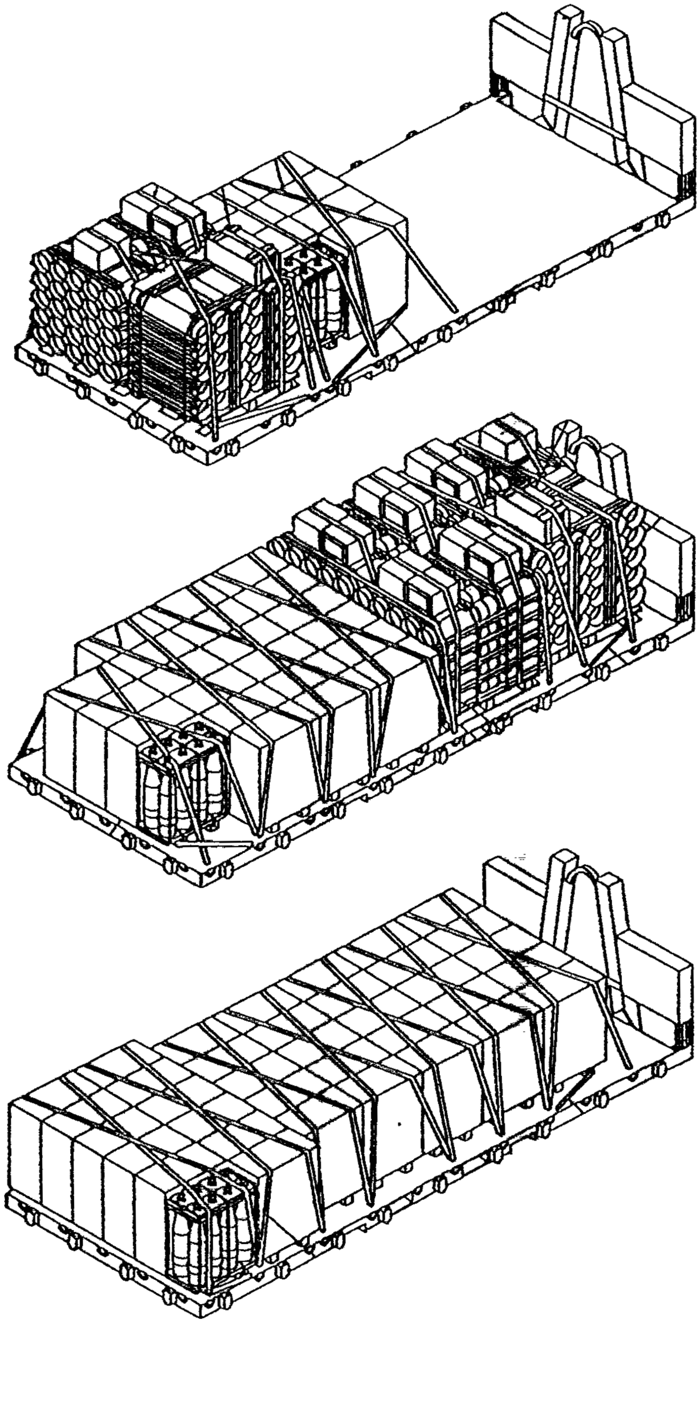

Figure 2. POSSIBLE PLS LOADING CONFIGURATIONS FOR 155 mm PROJECTILES

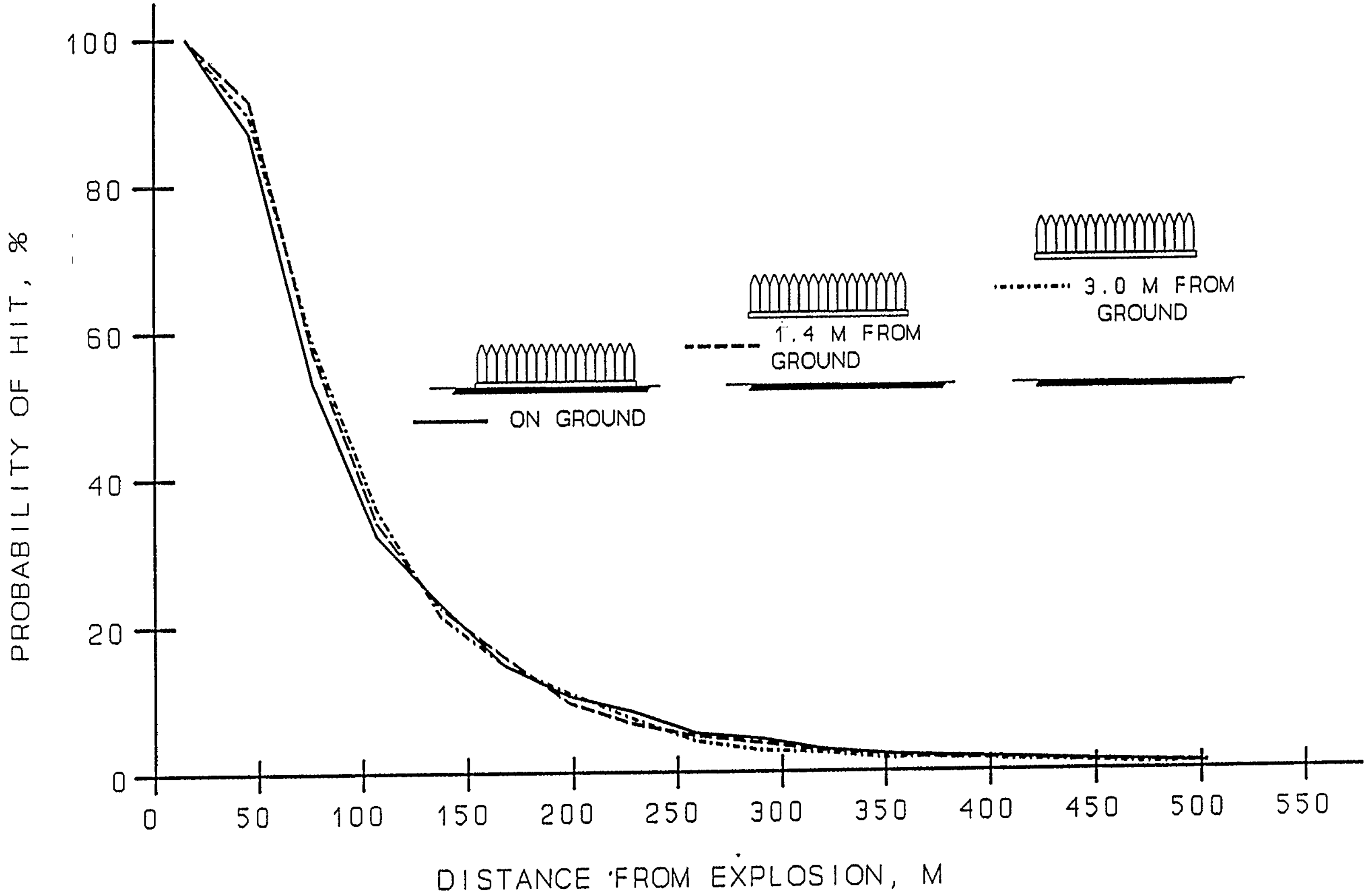


Figure 3. EFFECTS OF STANDOFF HEIGHT, 64 PROJECTILES

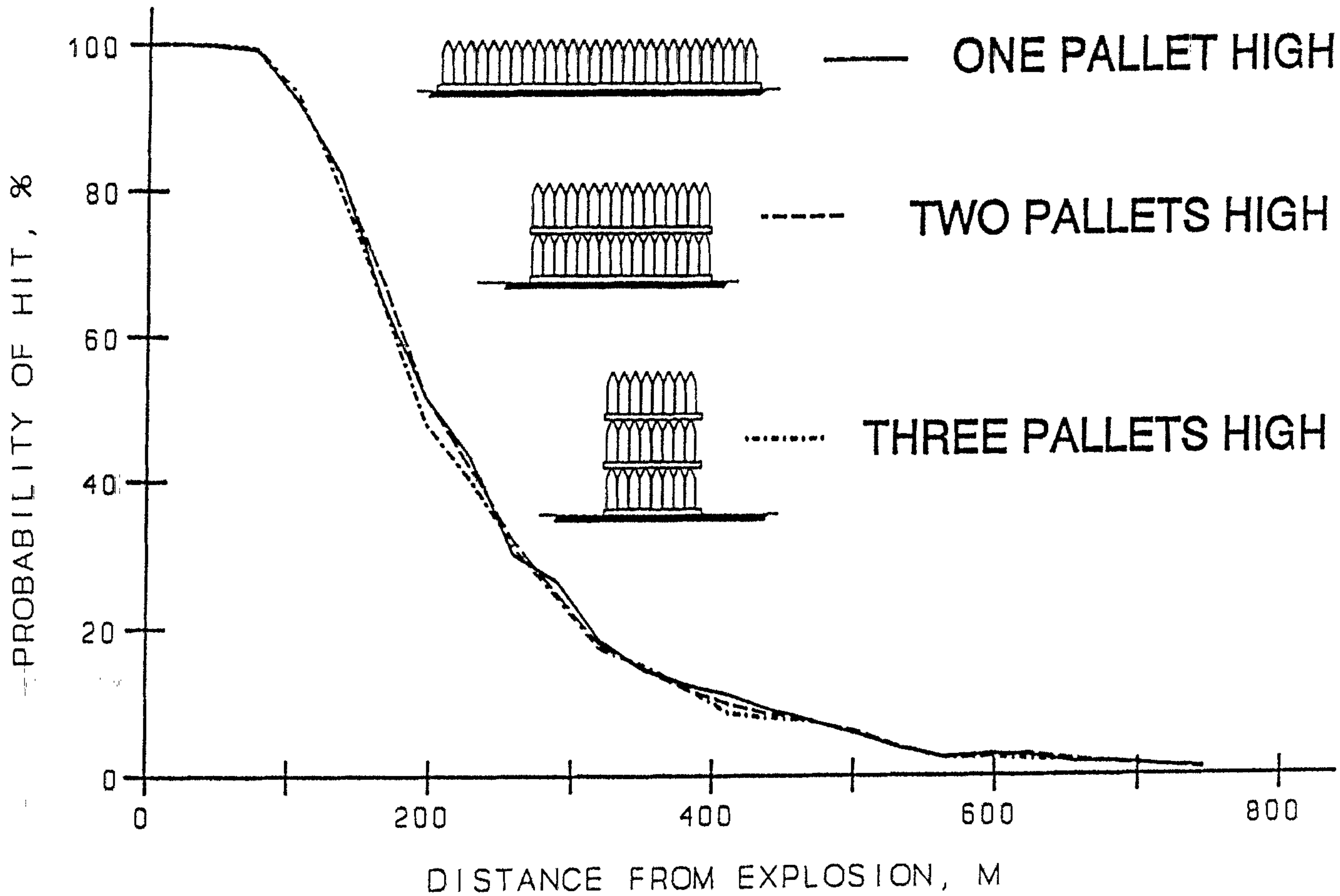


**Figure 4. EFFECTS OF STACK CONFIGURATION, 100 PROJECTILES**

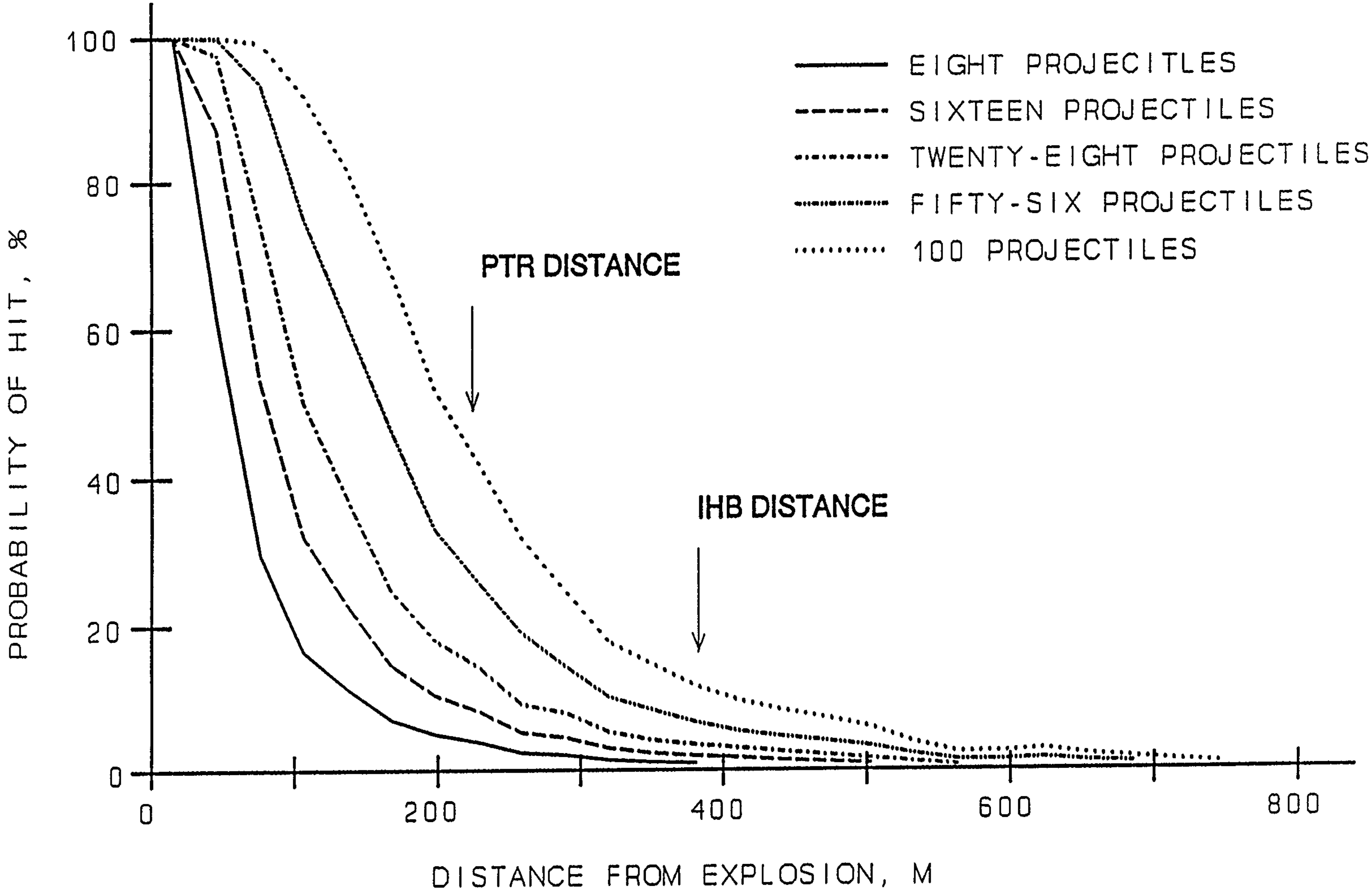


Figure 5. PROBABILITY OF FRAGMENT HIT ON STANDING MAN

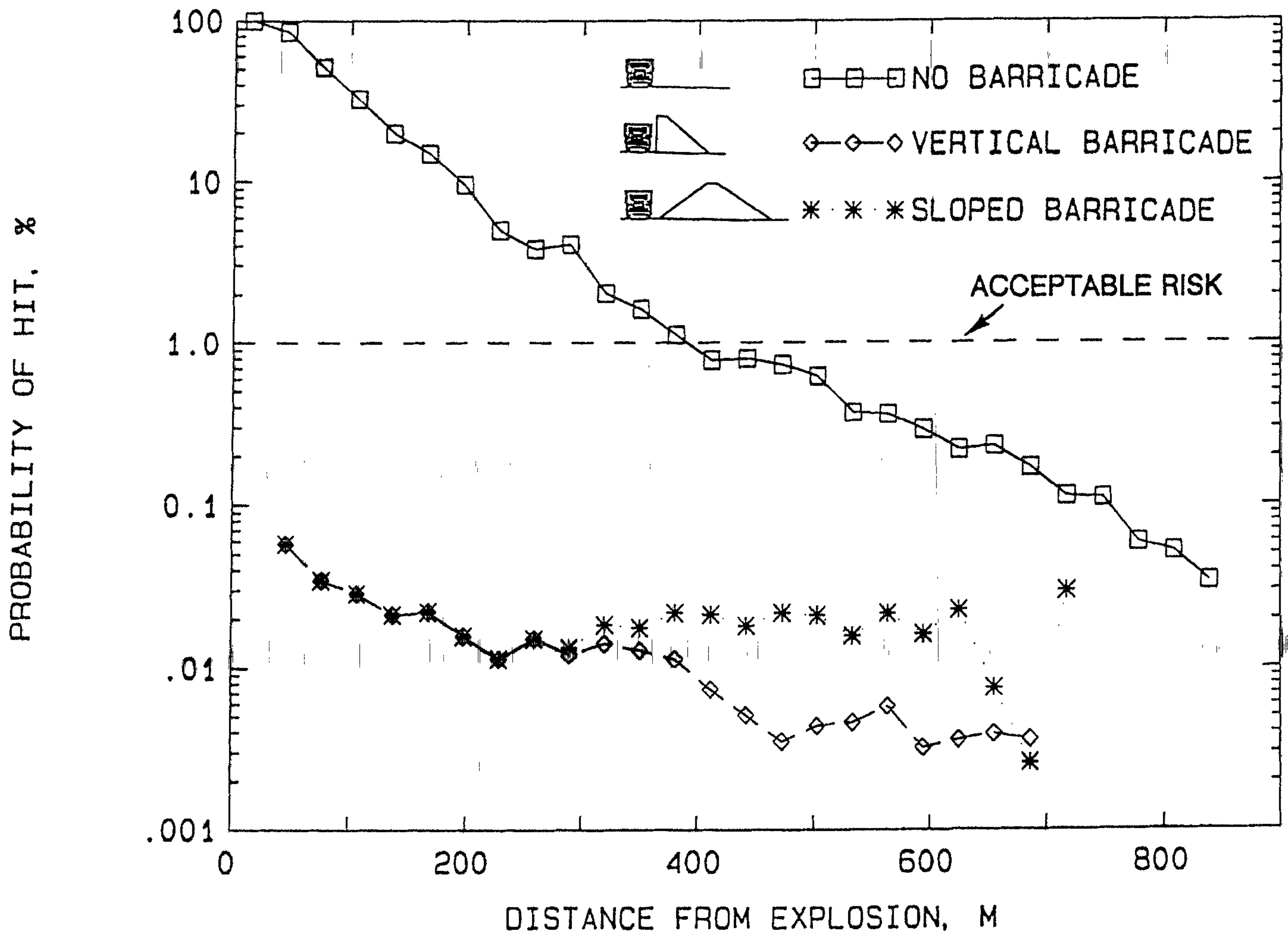


**Figure 6. EFFECT OF BARRICADES ON HAZARD TO STANDING MAN (AMMO TRUCK DETONATION)**

average radius of full demolition for near-miss events was significantly greater than that for direct hits. The reason is that for direct hits, blast must propagate through more obstructions (walls, ceilings, etc.) than for near misses (where blast may propagate unobstructed over large distances). This attenuation of blast by building components is represented in the facility models.

For buried detonations, damage to unprotected structures is based on the dimensions of the crater with respect to the facility. First floor components within the crater itself are assumed to be totally destroyed. Component damage then decreases with increasing distance. For shallow buried detonations which generate both airblast and cratering, the effects of each are assessed. Damage is determined as the greater of the two effects.

Following assessment of the primary weapon effects, the model assesses progressive structural collapse. As stated earlier, collapse rules are stored in the structure data file. The rules define loadbearing dependencies between components. Should a loadbearing wall on the second story have the first story wall below it destroyed by blast, the second story wall would be noted as unstable, and would be assessed to be collapsed. Currently, the model does not assess collapse from the dynamic loading of upper-level debris falling on lower levels.

4. Interior Environment

After analyzing the structure's response to the weapon, the model assess the relative severity of hazards to personnel in each room. Hazard environments assessed include overpressure, velocity (floor motion) primary fragments (bomb splinters), secondary projectiles (flying debris) and collapse (falling debris). Hazards are rated from each cause as either severe, moderate, light, or none. Each cause is described below.

Fast rising overpressure can injure personnel as the overpressure compression wave propagates through the body and reflects at internal air-tissue interfaces, such as the ears and lungs. Common injuries include ruptured ear drums and lung lesions. The model records the peak incident pressure and duration in each room as the blast propagates through the facility. These values are then compared to overpressure injury relationships described in the next section which relate a person's probability of sustaining a fatal, serious, or slight injury to the magnitude and duration of the overpressure. Based on this assessment, overpressure hazard is rated.

Personnel may be injured from being knocked off their feet and/or otherwise displaced as the floor heaves in response to the blast. This phenomena was designated velocity hazard. Velocity hazard is assessed by noting the state of a room's floor damage. It was assumed that increasing floor damage corresponded to increasing velocity hazard. Based on the final floor damage state, velocity hazard is rated.

Primary fragments are pieces of the weapon casing flying away from the detonation at extremely high velocities (5000 to 7000 fps). Primary fragments are the most significant injury mechanism for weapons detonating in the open against unprotected personnel. However, in structures, the literature indicates that even light partition walls provide surprisingly effective protection (Ref. 9). The severity of the primary fragment hazard is rated in the model based on the distance and number of intervening walls between the weapon and personnel at risk.

Secondary projectiles are created when a wall is breached or spalled by blast, causing numerous pieces of concrete, masonry, and other building materials to fly through the air. The severity of the secondary projectile hazard was rated based on the damage sustained by the walls of a room. It was assumed that increasing wall damage corresponded to increasing secondary projectile hazard. Based on the final damage state of all walls associated with a room, the secondary projectile hazard is rated.

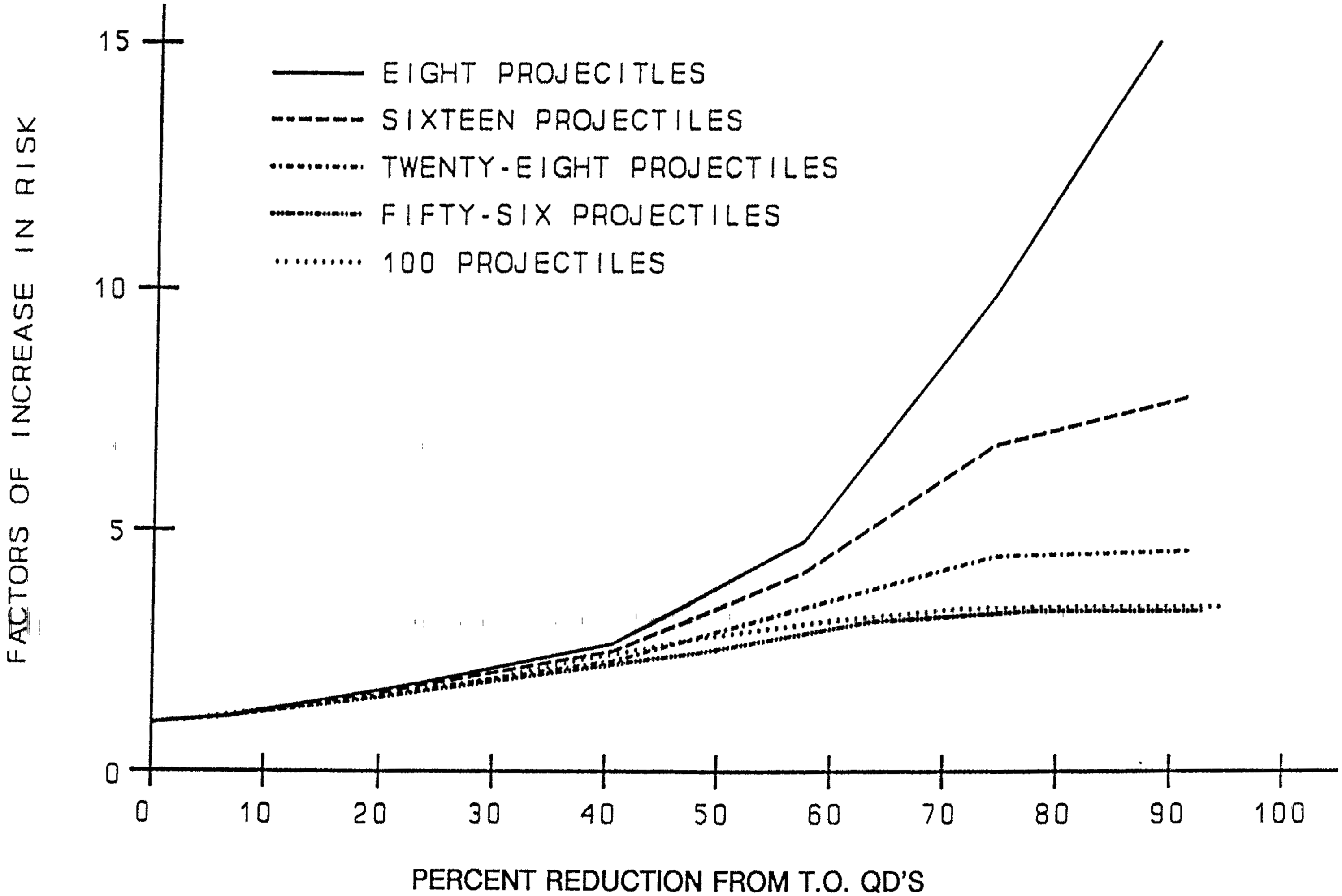


**Figure 8. INCREASE IN RISK DUE TO REDUCTION IN THEATER OF OPERATION QD'S (CH. 10 OF STANDARDS)**

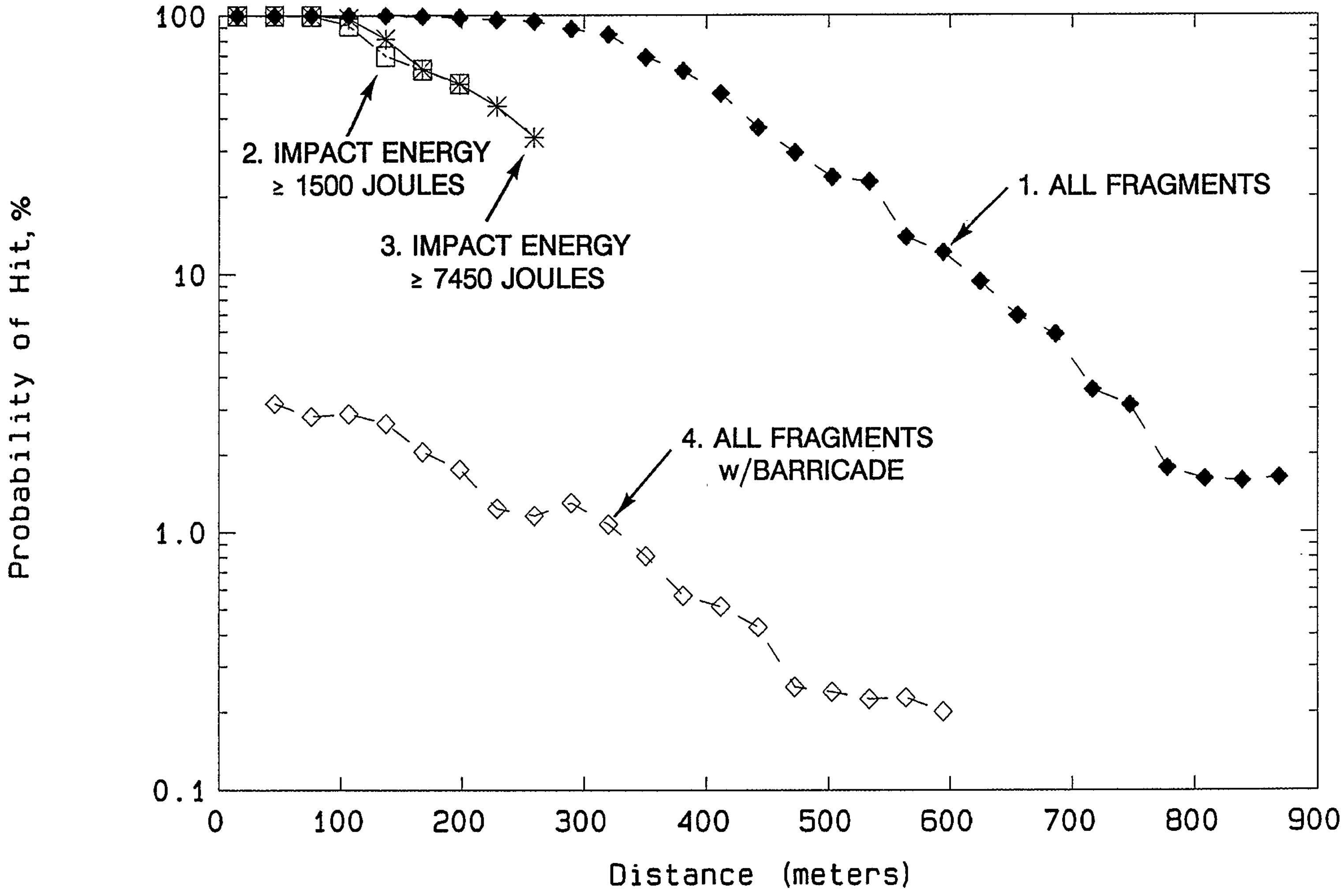


**Figure 9. PROBABILITY OF FRAGMENTS HITTING AMMO STACK**

TABLE 1.

INCREASE IN RISK DUE TO
Q-D VIOLATIONS FOR OPEN STORAGE
OF AMMO IN T.O.'S

| # PROJECTILES ON FACE | NEW, KG | Q-D,M* | FACTORS OF INCREASED RISK WITH: 30% QD REDUCTION | 50% QD REDUCTION |
|---|---|---|---|---|
| 8 | 447 | 180 | 2.2 | 3.8 |
| 16 | 894 | 180 | 2.0 | 3.4 |
| 28 | 1565 | 180 | 1.9 | 2.9 |
| 56 | 3192 | 203 | 1.9 | 2.5 |
| 100 | 5588 | 269 | 1.9 | 2.8 |

* FROM CHAP. 10 OF DD6055.9-STD